Pavement Heating

Frank Winters

An experimental, heated pavement has been constructed in Trenton, New Jersey, by the New Jersey Department of Transportation in order to develop improved methods for snow and ice control. The experimental pavement serves the dual purposes of (a) providing design data for snow-melting systems of embedded pipe, and (b) utilizing the earth both as a source of heat and as a means of storing solar energy. Wrought iron pipes of various diameters are embedded in portland cement concrete and bituminous concrete at depths of 2 and 4 in. and at various spacings. During snow and ice conditions an ethylene glycol solution is circulated through these pipes, and a record is kept of the flow rate and temperature drop of the heating fluid. The effectiveness of any particular combination of pipe diameter and spacing and depth of embedment may be evaluated by observing the rate at which the snow melts and by calculating the amount of heat supplied to the pavement by the embedded pipes. Heat is extracted from the earth by means of a buried heat exchanger consisting of 6,000 ft of 1¼-in. wrought iron pipe. The earth beneath the pavement was excavated to a depth of 13 ft, and 5 layers of pipe were laid with a horizontal and vertical spacing of 2 ft as the pit was backfilled. Heat is transferred to the surface by circulating the ethylene glycol solution through the buried pipe heat exchanger and then to the pipes embedded in the pavement.

The presence of snow or ice on highways, especially at interchanges, ramps, and bridge decks, often results in hazardous driving conditions and reduced traffic volumes. Conventional snow and ice control techniques may prove inadequate at these locations because of limited snow storage areas; the time lag between ice and snow formation and plowing, salting, and sanding operations; and alternate freezing and thawing of plowed or unplowed snow across superelevated ramps.

The ideal solution for the control of snow and ice at these problem locations is the use of heated pavement, capable of melting any snow or ice forming on the roadway. The major obstacle presently limiting the use of heated roads in New Jersey and elsewhere is the high operating cost of such an installation. The development of methods that would result in lower operating costs may justify the more extensive use of heated roadways.

The 2 principal types of heating systems currently in use are (a) a grid of electric resistance wires embedded in the pavement, and (b) a network of pipes embedded in the pavement, through which a hot fluid is circulated. In the latter system, the heat is usually supplied by a conventional gas- or oil-fired boiler or from commercially available steam. A unique exception is the use of natural hot springs in Klamath Falls, Oregon.

Prior work by the New Jersey Department of Transportation resulted in the construction of 2 electrically heated pavements, utilizing copper-sheathed, mineral-insulated resistance wires. The first installation was in 1961 on the approaches of Routes 1 and 9 to the Passaic River Bridge in Newark. This installation was later abandoned because of dislodgement of the cables in the bituminous concrete overlay. An improved installation was constructed in 1964 on 2 ramps and a bridge deck at the interchange of US-46 and US-17 in Teterboro. This system has operated satisfactorily for the past 5 years in melting any snow or ice on the pavement surface. Both installations were designed to dissipate 30 to 40 W/sq ft, which resulted in an annual operating cost of approximately 45 cents/sq ft of pavement surface.

This project was designed to experimentally evaluate the sources of ground and solar heat. Previous studies have shown that at a depth of 10 ft the soil temperature averages 55 F with a seasonal variation ±5 F and with the minimum occurring in March or April. At deeper depths the temperature gradually increases and exhibits less seasonal variation. To tap this heat source, a heat exchanger consisting of a network of pipes was buried in the earth through which an antifreeze solution was circulated. The antifreeze solution was then circulated through a grid of pipes embedded in the pavement, thus transferring heat from the earth to the pavement surface. During the summer months radiant energy from the sun often heats pavement surfaces to temperatures in excess of

PORTLAND CEMENT CONCRETE

PANEL No. 1 3/4" WROUGHT IRON PIPE	PANEL No. 3 1" PLASTIC PIPE	PANEL No. 5 1-1/4" WROUGHT IRON PIPE	PANEL No. 7 ELECTRIC RESISTANCE WIRES
PANEL No. 2 3/4" WROUGHT IRON PIPE	PANEL No. 4 1" WROUGHT IRON PIPE	PANEL No. 6 1-1/4" WROUGHT IRON PIPE	PANEL No. 8 ELECTRIC RESISTANCE WIRES

BITUMINOUS CONCRETE

Figure 1. Plan view of experimental area.

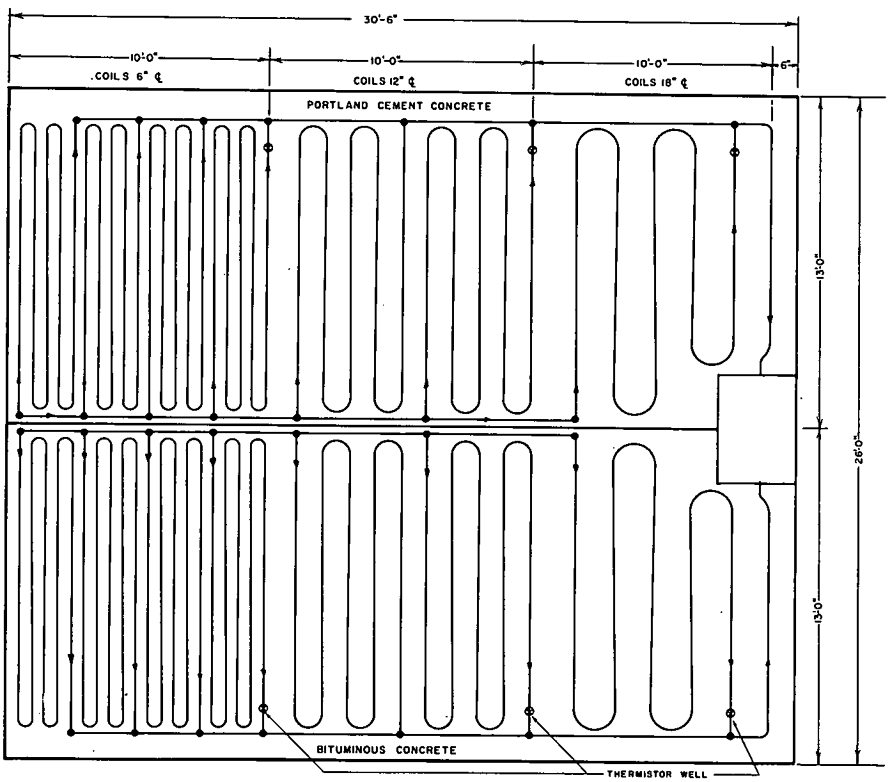

Figure 2. Typical heating panel.

100 F. This heat may be transferred from the pavement to the earth for storage by utilizing this same system of pipes.

Because construction of the experimental area was not completed until December 1969, this paper is limited to the evaluation of the use of ground heat. This report contains information on the design and construction of the experimental heated pavement and results obtained during the 5 major snowstorms from December 25, 1969, to February 26, 1970.

DESIGN OF PAVEMENT

The experimental heated pavement is located in the Fernwood Parking Lot adjacent to the Transportation Department Building in Trenton. The test area consists of 2 parallel lanes of pavement, each 13 ft wide and 123 ft long. One lane consists of four 9-in. thick slabs of portland cement concrete (pcc) while the other lane is constructed of 7 in. of bituminous concrete (bc) on a 6-in. macadam base. Each lane is subdivided into 8 separate test panels. Each panel is independent from the others so that a single malfunction will not affect operation of the entire system.

Pipes with nominal diameters of $^3/_4$, 1, and $1^1/_4$ in. are embedded at depths of 2 and 4 in. in the pavement of panels 1 and 2, 3 and 4, and 5 and 6 respectively (Fig. 1). In each of these panels the pipes are spaced on 6-, 12-, and 18-in. centers as shown in Figure 2. All pipe is standard weight wrought iron except in panel 3 where a polyvinyl chloride plastic pipe is used.

To serve as a reference, panels 7 and 8 contain vinyl insulated electric resistance wires embedded at a depth of 2 in. Both panels are evenly divided into 3 sections, designed to dissipate 20, 40, and 60 W/sq ft (Fig. 3). In addition, there is a 2-in. layer

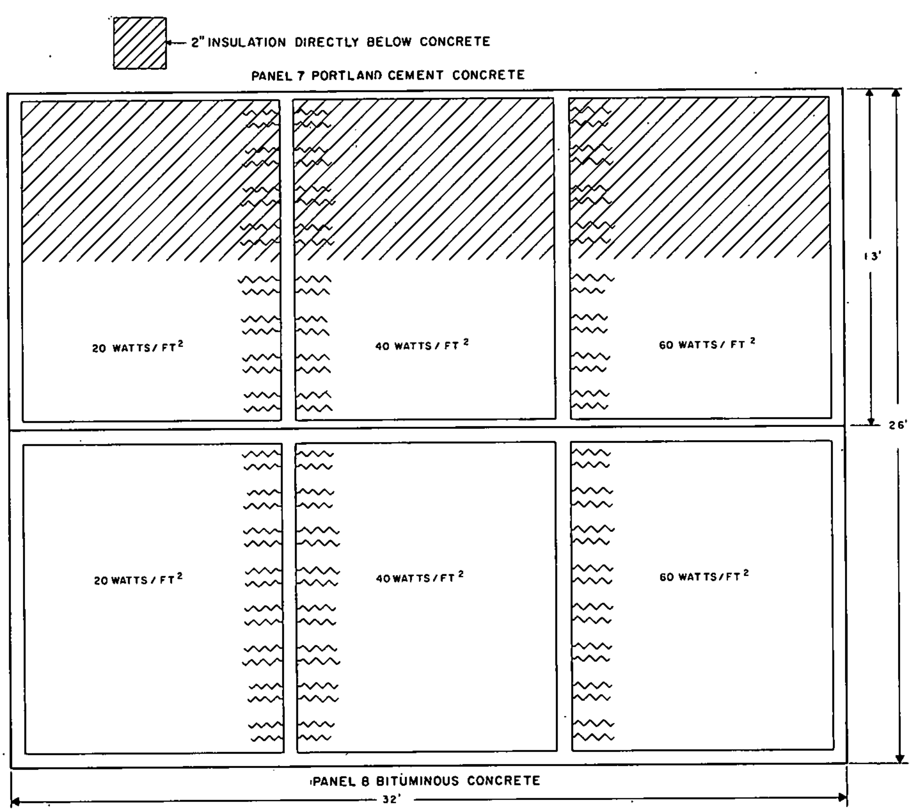

Figure 3. Typical electrically heated panel.

of glass foam insulation directly below half of the electrically heated portland cement concrete slab (panel 7). This insulation was included to test its effectiveness in reducing downward heat losses.

DESIGN OF HEAT EXCHANGERS

There are 3 heat exchangers (Fig. 4) each consisting of approximately 2,000 linear ft of $1\frac{1}{4}$-in. wrought iron pipe. Heat exchanger 1 is buried beneath panels 1 and 2, heat exchanger 2 is below panels 3 and 4, and heat exchanger 3 is below panels 5 and 6. Each heat exchanger is independent of the others and is connected to a separate pump that circulates an antifreeze solution of 50 percent water and 50 percent ethylene glycol to the 2 panels directly above it.

Because it is probable that much of the solar heat stored in the earth during the summer months may dissipate to the atmosphere or the surrounding earth, an 8-in. horizontal layer of insulation was provided above heat exchangers 1 and 2. In addition, a 6-in. layer of insulation completely encloses heat exchanger 2 (Fig. 5). This insulation is an expanded polystyrene foam having a density of 1.5 lb/cu ft for the 8-in. layer and 1.0 lb/cu ft for the 6-in. layer.

Heat exchanger 3 has not been insulated in order to serve as a control.

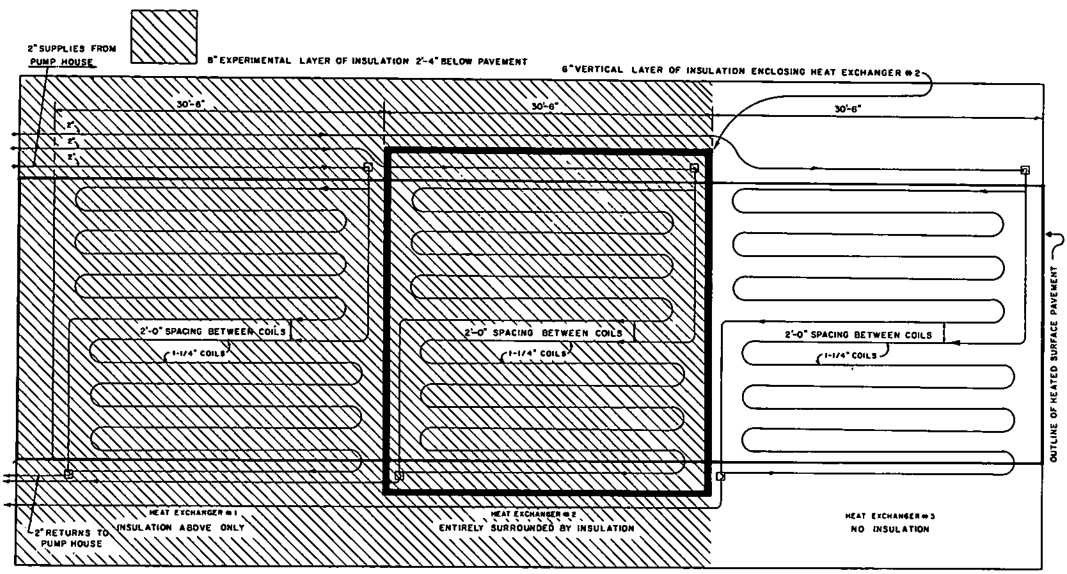

Figure 4. Plan view of heat exchangers.

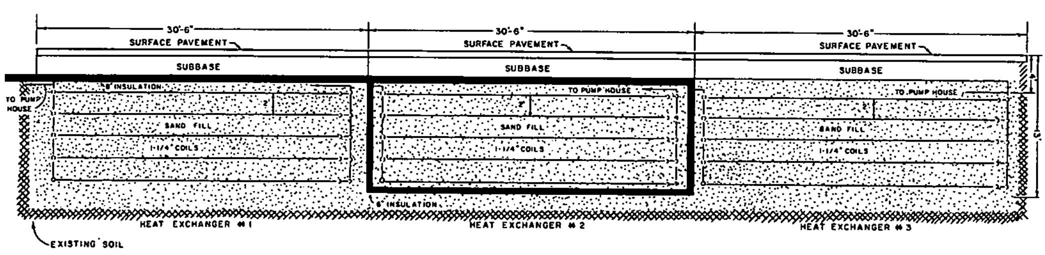

Figure 5. Section view of heat exchangers.

INSTRUMENTATION

Temperature of the earth, pavement, and water-glycol solution are monitored by 114 thermistors. Flow rate of the water-glycol solution is measured with 3 glass-tube, variable area flow meters.

CONSTRUCTION OF HEAT EXCHANGERS

Construction began on April 7, 1969. A 100- by 40-ft area was first excavated by bulldozer to a depth of 14 ft. All excavated material was trucked away because it was not considered suitable for backfill. A 6-in. layer of sand backfill was then spread over the entire area and compacted with a small hand-operated compactor (Table 1). In the area of heat exchanger 2, a 6-in. horizontal layer of polystyrene insulation was placed on the sand base (Fig. 6). This layer was constructed from 4-ft by 8-ft by 3-in. sheets of insulation with all joints overlapped. Another 6-in. layer of sand backfill was then placed over the entire area and compacted. Some difficulty was encountered in compacting the sand above the insulation because of its resiliency; however, as successive layers of backfill were placed, it was possible to achieve the specified compaction of at least 95 percent of maximum density. Prefabricated $1\frac{1}{4}$-in. wrought iron coils were then placed on the compacted sand (Fig. 7). All pipe joints were gas welded and tested for leaks by pressurizing the coils at 150 psi for 8 hours.

The same sequence of operations of placing and compacting backfill in 6-in. layers and the placement and testing of $1\frac{1}{4}$-in. coils with a 2-ft separation between layers continued until all 5 layers of the heat exchangers were completed.

The 6-in. thick vertical walls of insulation enclosing heat exchanger 2 were constructed of 4-ft by 8-ft by 3-in. sheets with all joints overlapped. Upon completion of backfill operations, an 8-in. horizontal layer of polystyrene insulation, constructed of 4-ft by 12-ft by 4-in. sheets, with all joints overlapped, was placed above heat exchangers 1 and 2.

Subsequent to placing the 8-in. layer of insulation, construction of the subbase and base courses for the surface pavement proceeded in a conventional manner. The only

TABLE 1
GRADATION REQUIREMENTS

Sand or Aggregate	Type	Square Sieve Size	Percent Passing
Sand backfill for heat exchangers	4E	$\frac{1}{2}$ in.	100
		No. 4	95 to 100
		No. 30	20 to 55
		No. 50	5 to 25
		No. 200	0 to 5
Aggregate for portland cement concrete	SPR 57	$1\frac{1}{2}$ in.	100
		1 in.	95 to 100
		$\frac{1}{2}$ in.	25 to 60
		No. 4	0 to 10
		No. 8	0 to 5
Aggregate for bituminous concrete	Mix 5	$\frac{1}{2}$ in.	100
		$\frac{3}{4}$ in.	90 to 100
		No. 4	60 to 80
		No. 8	41 to 51
		No. 50	14 to 22
		No. 200	4.3 to 8.8

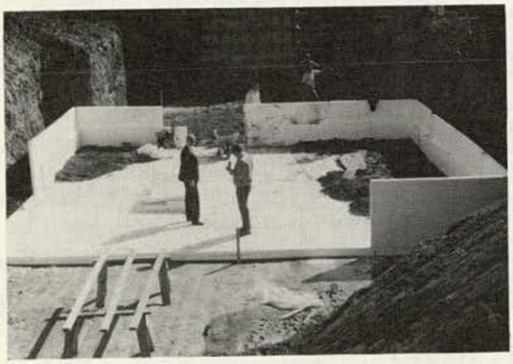

Figure 6. Polystyrene insulation enclosing heat exchanger 2.

Figure 7. Wrought iron coils on sand backfill in heat exchanger 2.

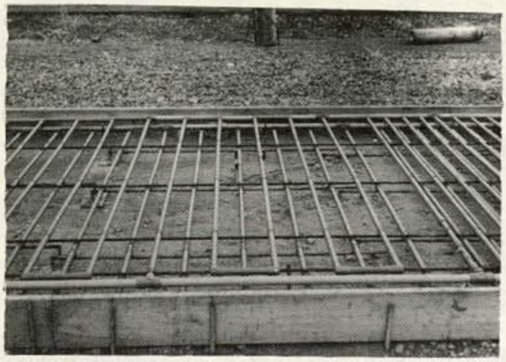

Figure 8. Plastic pipes in panel 3.

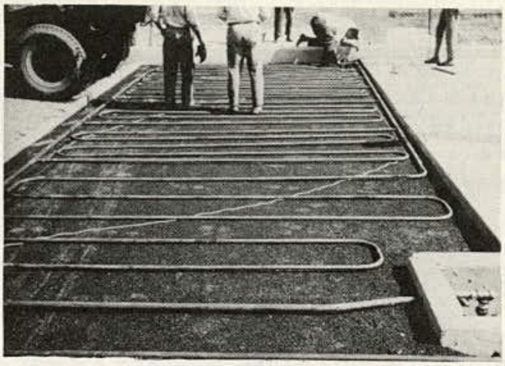

Figure 9. Wrought iron pipes in panel 2.

precaution taken was to maintain at least 6 in. of subbase material above the insulation during operation of heavy construction equipment.

CONSTRUCTION OF PORTLAND CEMENT CONCRETE

Upon completion of the subbase and base courses, forms for the pcc slabs were installed and the prefabricated wrought iron coils were placed within the forms at the specified heights by the use of "chairs," fabricated from ½-in. reinforcing rods. All pipe joints were gas welded and pressure tested at 150 psi for 8 hours. The coils for panel 3 were fabricated at the site from standard weight polyvinyl chloride plastic pipe (Fig. 8). All joints were solvent welded and pressure tested at 150 psi for 8 hours.

Portland cement concrete for this project was a standard mix as used in a typical New Jersey state highway. Placement, finishing, and curing of the concrete was accomplished according to standard state specifications for highway construction.

CONSTRUCTION OF BITUMINOUS CONCRETE

The bituminous concrete was placed in 4 lifts on a 6-in. macadam base course. After the first lift was placed and compacted, the prefabricated wrought iron coils to be embedded at a depth of 4 in. were placed on the hot surface, and placing and compaction of the second lift began (Fig. 9). This operation was again repeated for the next layer of coils to be embedded at a depth of 2 in. The bituminous concrete was placed mostly by hand, although a spreader was used for the bottom and top course. A 5-ton, 2-wheel roller was used to compact all 4 lifts. The only problem encountered was warping of the iron pipe due to heat from the hot mix. This may have resulted in the formation of voids either above or below some of the coils.

THERMISTORS

Thermistors with the heat exchangers were placed during the backfill operations. Thermistors in the earth adjacent to the heat exchangers were fastened to a wooden rod, at specified intervals, which was then inserted into a hole drilled to the proper depth. Positioning of the thermistors in both the pcc and the bc was by means of ½-in. wooden dowels driven into the base courses. The thermistors were inserted into holes drilled through the dowel and then secured with plastic tape. Figure 10 shows a section view of the heat exchangers and the depths and relative positions of the thermistors and the 1¼-in. pipes. The columns of thermistors shown are located in the center of each heat exchanger. The column of thermistors in the control section is located 40 ft from heat exchanger 3.

Construction and testing of the system was completed on December 19, 1969, at which time it became operational.

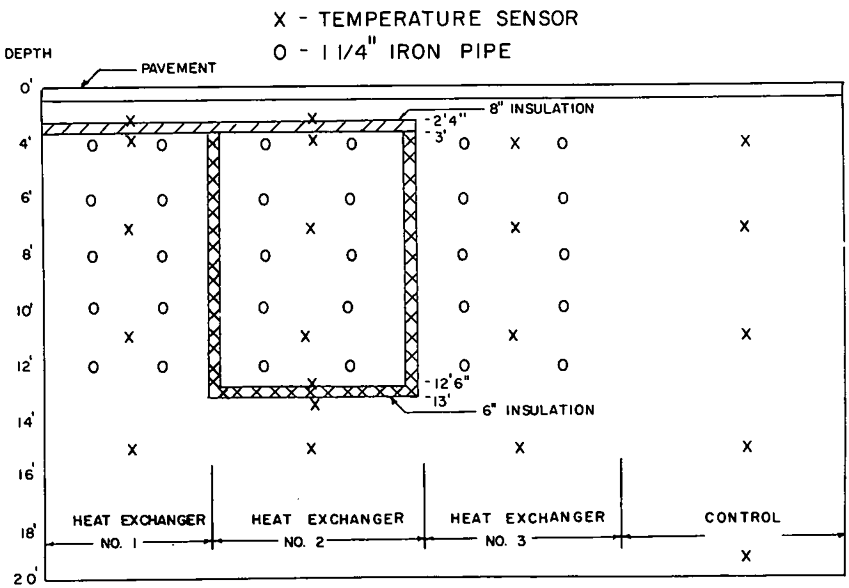

Figure 10. Section view of experimental area and thermistor location.

RESULTS

Results presented here are for 5 snowstorms, each of which resulted in an accumulation of 1 in. or more.

December 25, 1969

Snowfall began at approximately 4:00 p.m. and continued until early morning of December 26, resulting in a total snow accumulation of 3 to 4 in. All panels were activated at 9:55 p.m. December 25, at which time there was an accumulation of $2\frac{1}{2}$ in. of snow. Within an hour the snow above the wrought iron pipes spaced on 6-in. centers (panels 1 and 5) began to melt and turn to slush. Complete melting in these areas was accomplished by 4:15 p.m. December 26, 1969. At this time there was localized melting directly above the pipes spaced on 12- and 18-in. centers in the same panels. Although there was some melting on panel 3 (plastic pipe in pcc) and panels 2, 4, and 6 (wrought iron pipes in bc), the surface was still covered with 1 to 2 in. of snow.

Throughout the operation, melting of snow on panels 1 and 5 above the 6-in. spaced pipes was at least equivalent to the 20 W/sq ft area of panel 7 (electrically heated pcc).

The system was kept in operation until 10:00 a.m. on December 29.

January 6, 1970

All panels were put in operation at 3:30 p.m. in anticipation of snow. Snowfall began at 8:00 p.m. and continued throughout the night producing an accumulation of 3 in. At 11:00 p.m. all panels except the 40- and 60-W areas of panels 7 and 8 were snow-covered. At 10:00 a.m. the next day, the area above the pipes spaced on 6-in. centers in panels 1 and 5 was clear of snow (Figs. 11 and 12). There was also localized clearing of snow directly above the pipes spaced on 12- and 18-in. centers. Panels 2, 4, 5, and 6 were covered with 1 to 2 in. of snow.

It was again observed that the rate of snow melting above the 6-in. pipes in panels 1 and 5 was at least equivalent to the electrically heated area dissipating 20 W/sq ft.

The system was turned off at 9:30 p.m., January 7.

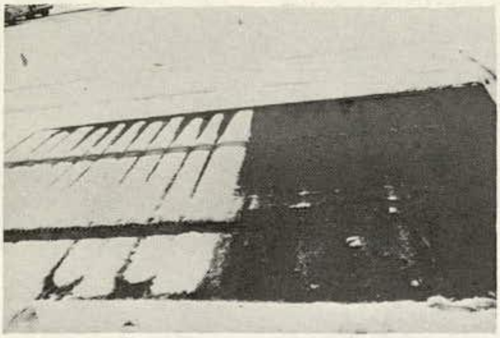

Figure 11. Panel 1 at 10:00 a.m. on January 7, 1970—pipes on 6-in. centers.

Figure 12. Panel 1 at 1:15 p.m. on January 7, 1970—pipes on 6-, 12-, and 18-in. centers.

January 12, 1970

One inch of snow fell during the night, and all panels were put in operation at 10:15 a.m., January 13. Clearing of the area above the pipes spaced on 6-in. centers in panels 1 and 5 was complete by 2:15 p.m. At this time panels 2, 3, 4, and 6 were still snow-covered.

The system was turned off at 11:45 p.m., January 13.

January 20, 1970

Snow flurries began at 5:00 p.m. and continued until 12:00 p.m. producing an accumulation of $2\frac{1}{2}$ in. Panels 1, 2, 3, 4, 7, and 8 were activated at 11:45 p.m., January 20, at which time the air temperature was 28 F. During the night melting had taken place above the 6-in. pipes in panel 1. Above the electrically heated panels 7 and 8, however, all the areas refroze except the 60-W/sq ft areas of panels 7 and 8 when the air temperature dropped below 15 F.

The system was kept in operation until 11:20 p.m. on January 21 at which time the area above the pipes spaced on 6-in. centers of panels 1 and 2 was clear and dry.

February 14, 1970

Approximately 1 in. of snow fell during the day. Panels 1, 2, 3, 4, 7, and 8 were put in operation at 12:45 p.m., February 15. At 1:30 a.m., February 16, the area above the 6-in. pipes in panel 1 was 75 percent clear of snow. Panels 2, 3, and 4 were still snow-covered at this time. At 10:10 p.m., February 16, all areas of panels 1 and 2 were clear and dry.

The system was turned off at 10:00 a.m., February 17, at which time panels 3 and 4 were completely clear of snow.

FINDINGS

During all of these snowstorms, the rate of snow melting on the uninsulated section of the electrically heated pcc panel 7 was greater than on the insulated area. The 20 W/sq ft of the uninsulated area appeared equivalent to the 40 W/sq ft area of the insulated area.

Table 2 gives the amount of heat dissipated per square foot of pavement surface, and the corresponding surface temperature for the 5 major snowstorms. The heat dissipated was calculated from measurements of the input and output temperatures of the heating fluid for each spacing of coils in the various panels and from the flow rate of the heating fluid. The data were collected under approximately the same conditions. The hours of operation of the system were in the range of 7 to 12 hours, and the pavement surface was at least wet and in most instances covered with snow.

TABLE 2

HEAT DISSIPATED AND SURFACE TEMPERATURE OF HEATED PAVEMENT, ALL SNOWSTORMS

Date, Time, and Hours in Operation	Air Temperature (deg F)	Pipe Diameter (in.)	Heat Dissipated by Pipe Spacing (Btu/sq ft)						Surface Temperature by Pipe Spacing (deg F)					
			Portland Cement Concrete			Bituminous Concrete			Portland Cement Concrete			Bituminous Concrete		
			6 in.	12 in.	18 in.	6 in.	12 in.	18 in.	6 in.	12 in.	18 in.	6 in.	12 in.	18 in.
12-26-69		3/4	105	60	26	50	—	18	34.6	33.9	32.3	36.5	33.1	32.6
10:05 a. m.	34.4	1	72	42	13	69	46	35	33.2	32.3	32.1	36.6	33.3	32.7
12		1 1/4	115	51	19	—	19	5.8	33.7	32.5	—	36.0	33.5	33.6
1-6-70		3/4	75	42	20	37	—	12	33.9	32.6	32.2	35.6	32.9	32.3
11:15 p. m.	29.0	1	51	26	11	43	27	9	32.8	32.3	32.1	35.1	—	32.6
7		1 1/4	80	38	15	49	17	6	33.2	32.4	—	35.5	33.3	33.3
1-12-70		3/4	82	48	22	39	—	12	32.8	32.3	31.0	28.1	32.1	31.0
8:00 p. m.	27.5	1	50	31	10	45	35	10	32.6	27.5	26.6	34.7	28.0	28.2
12		1 1/4	93	46	18	65	23	8	32.2	28.5	—	33.9	29.3	35.1
1-21-70		3/4	98	53	24	51	—	15	31.2	32.2	30.6	35.0	32.1	30.6
9:05 a. m.	16.0	1	47	30	10	41	29	8	32.6	28.2	28.7	34.7	32.0	30.5
9		1 1/4			not operational				28.7	28.1	—	29.0	28.4	28.4
2-16-70		3/4	81	54	25	35	—	14	34.6	32.9	32.7	35.5	33.8	33.8
1:30 a. m.	33.4	1	52	30	12	38	29	10	33.5	32.3	32.3	34.6	33.1	33.3
12		1 1/4			not operational				32.0	32.1	—	32.5	32.4	32.7

TABLE 3

HEAT DISSIPATED AND SURFACE TEMPERATURE OF HEATED PAVEMENT, DECEMBER 25, 1969, SNOWSTORM

Date and Time	Air Temperature (deg F)	Pipe Diameter (in.)	Heat Dissipated by Pipe Spacing (Btu/sq ft)						Surface Temperature by Pipe Spacing (deg F)					
			Portland Cement Concrete			Bituminous Concrete			Portland Cement Concrete			Bituminous Concrete		
			6 in.	12 in.	18 in.	6 in.	12 in.	18 in.	6 in.	12 in.	18 in.	6 in.	12 in.	18 in.
12-25-69		3/4	132	76	31	81	—	21	33.7	30.3	29.4	33.6	30.6	30.4
11:15 p. m.	27.4	1	87	49	18	96	62	20	32.4	29.5	29.0	34.2	30.5	29.3
		1 1/4	144	63	24	101	30	10	33.3	31.6	—	34.0	—	29.9
12-26-69		3/4	105	60	26	50	—	15	34.6	32.6	32.3	36.5	32.1	32.6
10:05 a. m.	34.4	1	72	42	13	69	46	35	33.2	32.3	32.1	36.6	33.3	32.7
		1 1/4	115	51	19	—	19	6	33.7	32.5	—	36.0	33.5	33.6
12-28-69		3/4	46	42	17	33	—	11	47.2	33.2	34.5	38.4	35.6	33.1
11:00 a. m.	37.2	1	43	31	11	46	30	10	39.0	34.0	32.2	37.1	34.8	32.9
		1 1/4	17	24	7	34	9	2	47.0	33.6	—	36.8	34.1	33.0
12-29-69		3/4	33	30	15	12	—	7	43.8	38.0	31.8	36.5	32.9	31.4
9:30 a. m.	34.8	1	34	26	9	21	22	6	40.8	31.7	30.6	44.2	—	31.4
		1 1/4	36	30	11	48	18	6	43.8	39.8	—	42.4	34.2	31.5

TABLE 4

HEAT DISSIPATED AND SURFACE TEMPERATURE OF HEATED PAVEMENT, FEBRUARY 16, 1970, SNOWSTORM

Date and Time	Air Temperature (deg F)	Pipe Diameter (in.)	Heat Dissipated by Pipe Spacing (Btu/sq ft)						Surface Temperature by Pipe Spacing (deg F)					
			Portland Cement Concrete			Bituminous Concrete			Portland Cement Concrete			Bituminous Concrete		
			6 in.	12 in.	18 in.	6 in.	12 in.	18 in.	6 in.	12 in.	18 in.	6 in.	12 in.	18 in.
2-15-70		3/4	97	62	29	44	—	18	33.7	32.6	32.5	34.6	33.1	32.9
3:30 p. m.	36.0	1	54	30	13	46	32	1	32.5	32.2	32.2	34.2	32.6	33.0
		1 1/4			not operational				32.0	32.0	—	32.4	32.3	32.6
2-16-70		3/4	81	54	25	35	—	14	32.6	32.9	32.7	35.5	33.8	33.8
1:30 a. m.	33.4	1	52	30	12	38	29	10	33.5	32.3	32.3	34.6	33.1	33.3
		1 1/4			not operational				32.0	32.1	—	32.5	32.4	32.7
2-16-70		3/4	12	25	15	35	—	14	49.5	45.0	43.9	37.0	35.2	35.6
1:15 p. m.	36.5	1	28	21	9	22	22	7	46.4	33.0	32.8	40.2	35.2	34.5
		1 1/4			not operational				32.1	34.3	—	32.6	33.2	32.9
2-16-70		3/4	115	76	41	92	—	30	36.0	32.9	31.0	32.8	30.2	30.1
10:15 p. m.	29.9	1	46	29	13	28	22	7	31.5	28.8	28.2	32.0	28.5	29.1
		1 1/4			not operational				28.6	28.8	—	29.2	26.0	28.0
2-17-70		3/4			not operational				36.1	36.4	34.5	36.0	38.0	32.7
10:45 a. m.	37.1	1	26	21	9	16	17	6	45.1	38.1	32.7	38.0	40.3	35.8
		1 1/4			not operational				31.4	33.3	—	31.1	31.9	32.0

Table 3 gives the heat dissipated and surface temperature during the snowstorm beginning December 25, 1969. The large variations in the heat dissipated per square foot of surface pavement can be attributed to several factors including surface condition (snow-covered, wet, or dry), air temperature, and amount of sunlight incident on the pavement surface.

Table 4 gives the heat dissipated and surface temperature during the snowstorm of February 16, 1970. Again, there are large variations in the amount of heat dissipated.

The temperatures of the fluid of the 3 heat exchangers for the dates and hours of operation are given in Table 5.

TABLE 5

TEMPERATURE OF HEAT EXCHANGER FLUID

Date	Hours of Operation	Temperature (deg F)		
		Heat Exchanger 1	Heat Exchanger 2	Heat Exchanger 3
12-25-69	2	52.0	52.0	49.0
12-29-69	71	46.0	48.0	46.0
1-6-70	80	47.0	47.0	46.0
1-7-70	102	45.0	45.0	44.0
1-13-70	130	43.0	43.0	42.0
1-21-70	140	44.0	43.0	—[a]
1-23-70	160	42.5	42.0	—[a]
2-15-70	170	42.0	41.0	—[a]
2-16-70	200	42.0	40.0	—[a]

[a]Not operational after 1-13-70 due to minor leak at a valve.

Figure 13 shows temperature data of the existing soil 40 ft from the closest heat exchanger.

Figures 14, 15, and 16 show the variation in soil temperature at depths of 3, 7, and 11 ft for heat exchangers 1, 2, and 3 and the control section. The soil temperature of heat exchanger 3 (no insulation) shows a gradual increase after operation was discontinued on January 13, 1970.

Figure 17 shows the soil temperature above and below the 8-in. layer of insulation located above heat exchanger 2. At first it would appear that 8 in. of insulation has little effect on the soil temperature at a depth of 3 ft; however, consideration must be

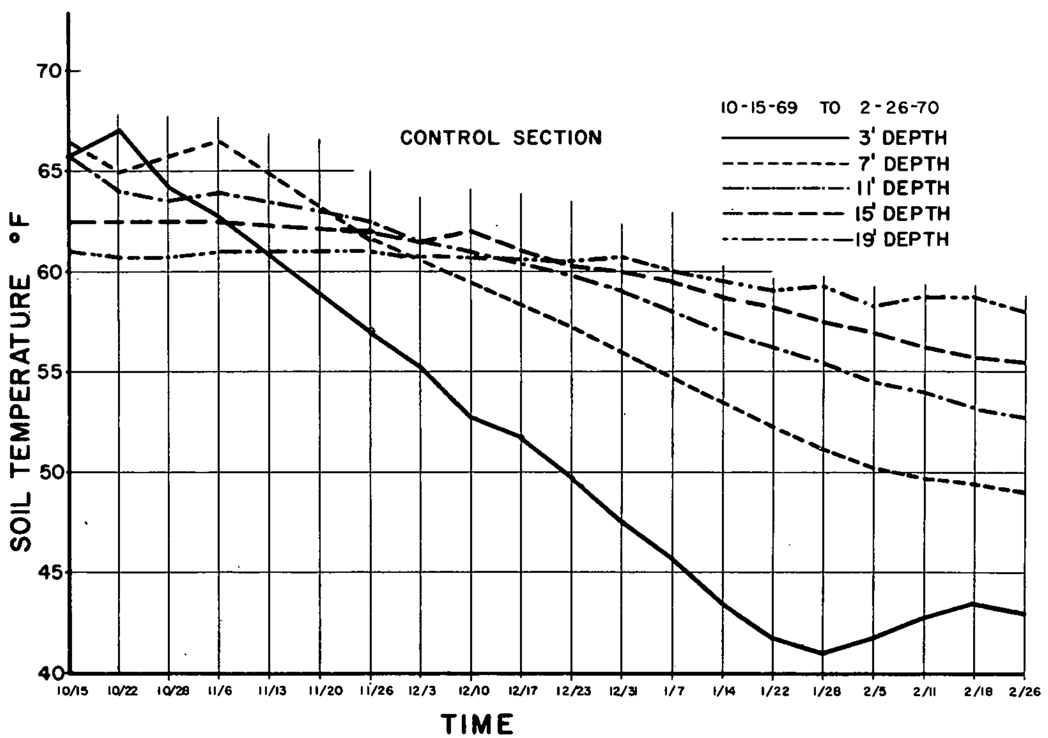

Figure 13. Temperature of existing soil at depths of 3, 7, 11, 15, and 19 ft.

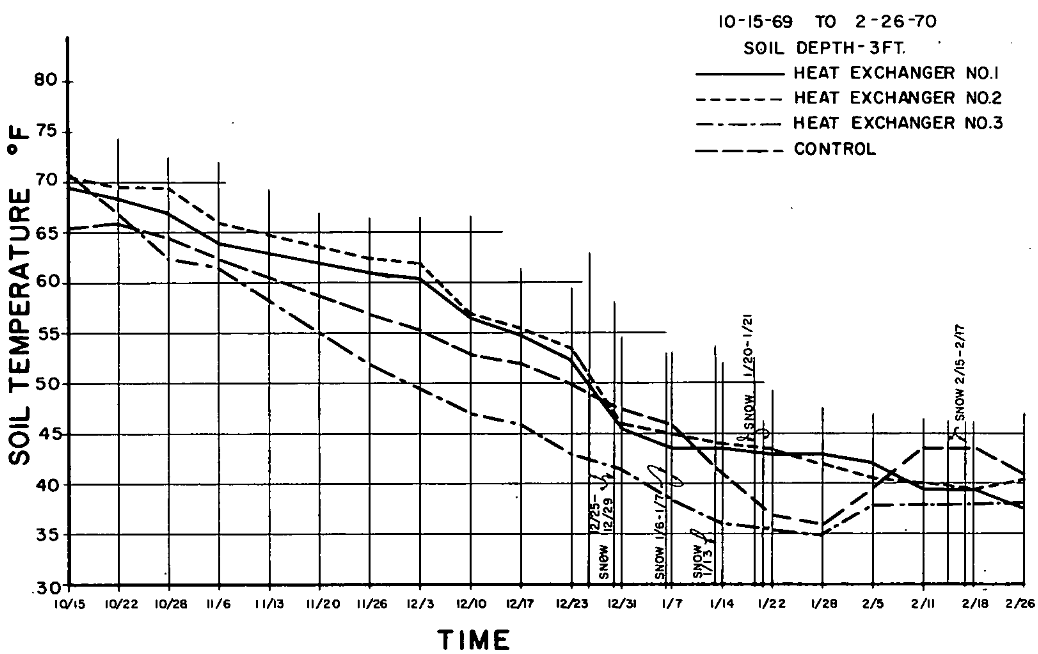

Figure 14. Soil temperature of heat exchangers at depth of 3 ft.

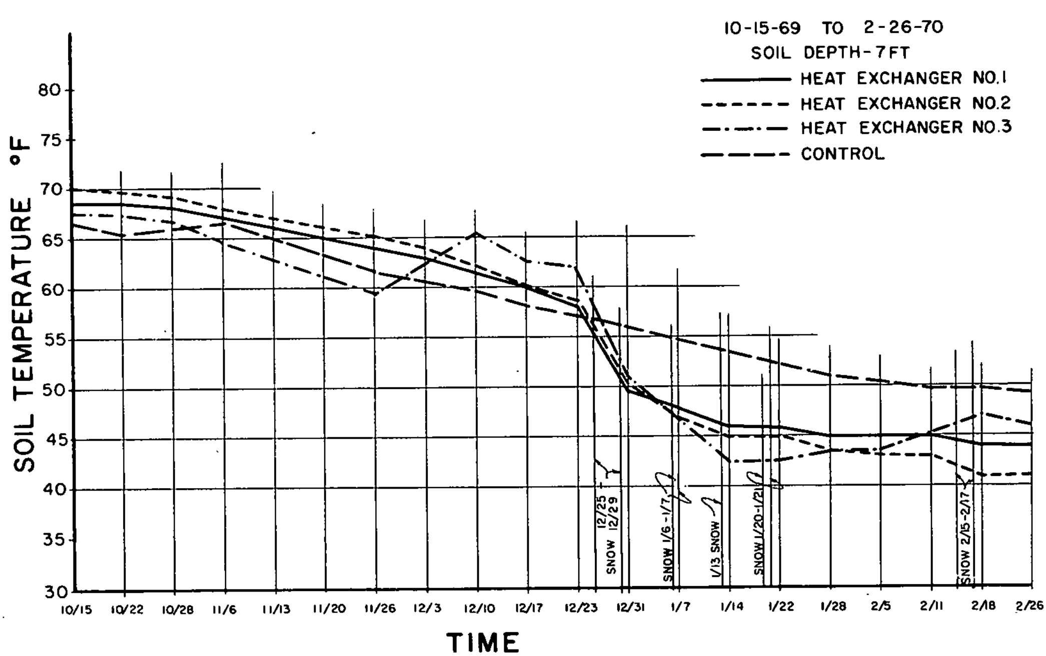

Figure 15. Soil temperature of heat exchangers at depth of 7 ft.

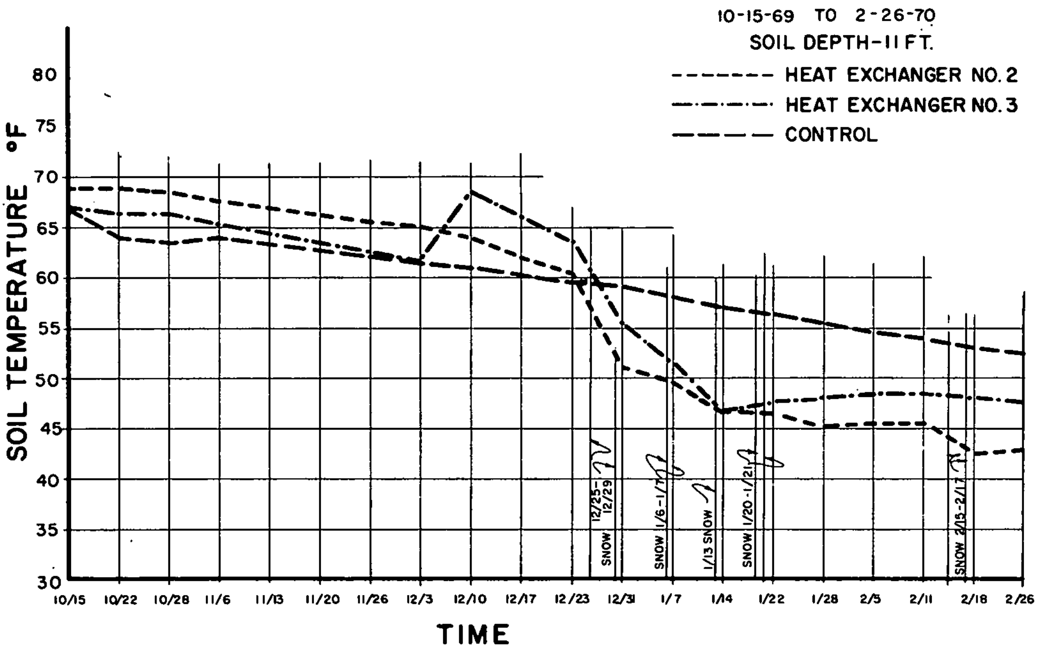

Figure 16. Soil temperature of heat exchangers at depth of 11 ft.

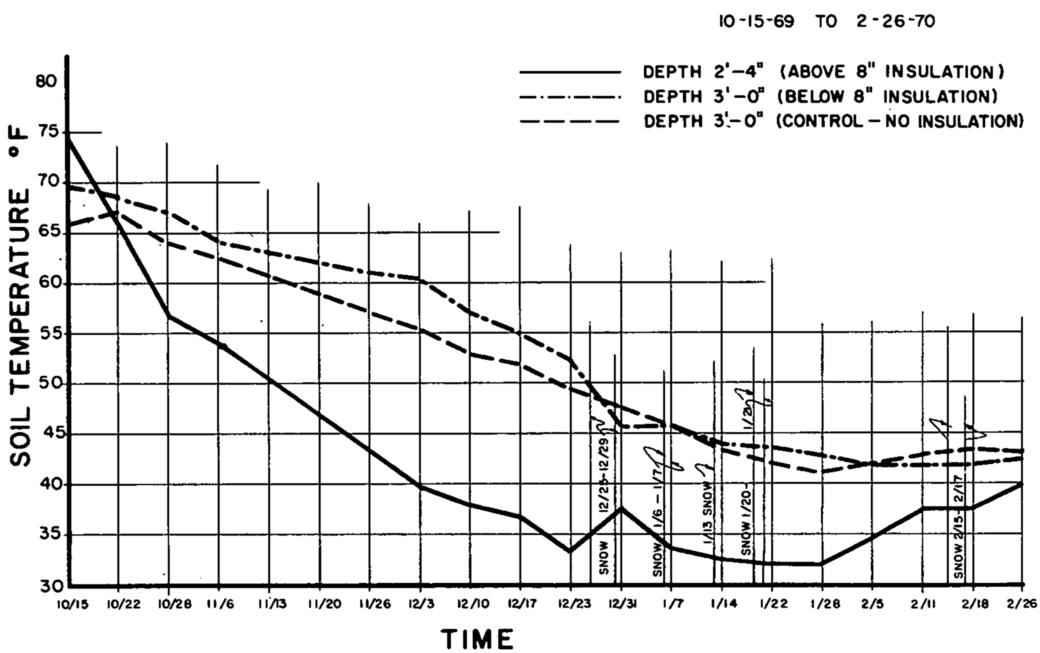

Figure 17. Soil temperature above and below 8 in. of insulation.

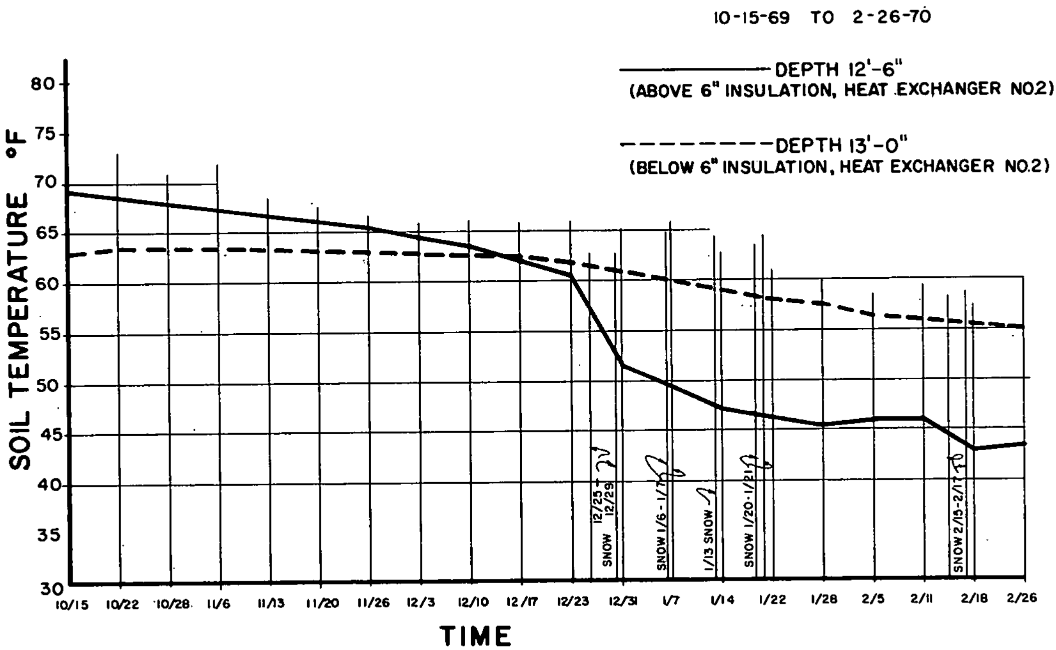

Figure 18. Soil temperature above and below 6 in. of insulation at a depth of 13 ft.

given to the fact that heat exchanger 2 extracted considerable heat during 200 hours of operation.

Figure 18 shows the effect of the 6-in. layer of insulation below heat exchanger 2. The insulation appears to be very effective in restricting the flow of heat as can be seen from the 10 F temperature differential after heat exchanger 2 was first put in operation on December 25, 1969.

CONCLUSIONS

1. The following combination of factors was found to be an effective means for melting snow and ice on pavement surfaces: (a) wrought iron pipes embedded at a depth of 2 in. in portland cement concrete; (b) spacing of pipes on 6-in. centers; (c) nominal diameter of wrought iron pipes of $^3/_4$ to $1^1/_2$ in.; (d) temperature of the heating fluid in the range of 42 to 52 F; and (e) air temperature above 15 F.
2. This combination of factors produced approximately 100 Btu/sq ft of pavement.
3. Based on the amount of heat dissipated per square foot of pavement, under identical conditions, the thermal conductivity of the portland cement concrete, as used in this experiment, was twice that of the bituminous concrete.
4. The use of pipes buried in the earth can be an effective means of extracting sufficient heat for use in melting snow and ice on pavements.
5. For this particular experiment, the rate of heat extracted from the earth by 1 ft of $1^1/_4$-in. wrought iron pipe was approximately 22 Btu/hr.
6. The use of 2 in. of insulation directly below a portland cement concrete pavement was not an effective means of improving the efficiency of embedded heating elements. Insulation restricted the natural flow of heat from the subbase to the pavement such that the rate of snow melting on the insulated portion of the heated pavement was not as rapid as on the uninsulated portion.

Informal Discussion

Don L. Spellman

Do you have any measurements to indicate what percentage of the heat sink capacity was used up during each storm period? In other words, how many times can you repeat this?

Winters

We do not know the limits yet; we operated only 200 hours, and it was still melting snow successfully. We do have temperature measurements of the soil, and we can tell when the system is operating because we can see a distinct drop in the soil temperature.

Spellman

Was the volume of the heat sink that you had big enough to take care of one winter's operation?

Winters

Yes.

Samuel H. Nitzberg

What was the water table?

Winters

When we excavated it was greater than 14 ft, but later it came up to 3 ft or so.

Lawrence H. Chenault

For about 5 years now we have been using thin-walled polyethylene pipe for snow-melting systems with no problems at all, but we really have not had an opportunity to get a direct comparison of the performance of the plastic versus that of the metal. Do you have any comments on that?

Winters

In our system the plastic is definitely not as effective as the metal, but that is mainly because the temperature of the fluid we are using is very low. The lower thermal conductivity of this plastic pipe requires a higher flow of heat. If we were using temperatures up around 100 F, I think the effect of the decreased thermal conductivity of the plastic pipe would be negligible.

Chenault

The limited tests that we did run were a comparison of copper pipe and plastic, and we determined that the major factor in heat transfer ability of the total system was dominated by the concrete wall around the pipe and that the coefficient of thermal conductivity of the 2 pipe materials became insignificant in this whole system.

Winters

Normally it would if you are using temperatures higher than what we were using. Above 100 F, the limiting factor is the thickness of the concrete and its thermal conductivity. For our low temperature system, the lower thermal conductivity of the plastic pipe reduced its heat output by half that of a comparable wrought iron pipe.

Chenault

I am talking about 130-deg water temperature.

Winters

Then it would probably have no effect.

Guenther E. Frankenstein

I think you said your operating cost was 45 cents/sq ft. How does this compare with the cost of a direct electrical heating system such as the one Dave Minsk is working on at USACRREL? And also, how do you account for the lack of effectiveness of the bituminous concrete? You apparently had some sunny days that should have warmed the black surface; so there should have been melting from both directions, yet there was none.

Winters

Yes, the blacktop would normally pick up the radiation from the sun, but when it is covered with snow it reflects it. The thermal conductivity of the bituminous concrete, from the measurements we made, is only half that of portland cement concrete. As for the cost, that 45 cents/sq ft was based on a 5-year record for an electrically heated system, which has nothing to do with the present system. Approximately half of that cost is the demand charge by the utility company. We paid several thousand dollars just to have electricity there whether we used it or not. The other half is the cost of operating the system. I do not know how this compares with the costs of the system Dave is working on.

Frankenstein

I would disagree with your statement that when the blacktop is covered with snow it would not pick up the radiation. You are talking about 1, 2, or 3 in. of snow cover. We have found in tests in Alaska that with the same amount of snow at your temperatures it would still have an effect.

Winters

From our observations, the amount of solar radiation picked up by the blacktop when covered with snow is negligible.

David Minsk

I think it is awfully difficult to make any comparisons of cost in experimental installations. They are not representative of an actual installation because of so many variables. The cost of operation, for instance, of our installation was not tallied to as precise an extent as that of Frank Winters'. We operated it for only 2 years, and in that time we did not evaluate the actual cost; but we do know the number of watt-hours required. I do not recall the figures offhand, but I would say they were on the order of magnitude of the New Jersey tests in spite of the heavier snowfall that we had because of the more rapid placement of the thermal energy right where it was needed—at the interface. We did not have to contend with the increased thermal conductivity of the 1, 2, or 3 in. of pavement placed between the heating elements and the surface.

Winters

I want to mention that the 45 cents/sq ft was for the operation of the system that was constructed in 1964. For the present installation we do not have any accurate figures on cost, other than that the cost of heating the area by the pipes is about $\frac{1}{100}$ that of melting the snow electrically because all we have to do is run three $\frac{1}{4}$-hp pumps compared to using 50,000 to 100,000 watts.

Spellman

Next summer you should be able to store some solar energy. What temperature do you expect to get compared to the 52 F you were speaking of?

Winters

The temperature of the pavement should reach 120 F for the bituminous concrete. We have already noticed that on a sunny day the temperature of bituminous concrete at a depth of 2 or 3 in. is 10 to 20 deg higher than that of the portland cement concrete. I do not know whether the heat sink will get to 120 deg, but I would expect it to be at least 30 deg higher than the natural soil temperature.

Chenault

I have one comment on operating cost based on our experience in snow melting. If gas fuel at 8 cents/therm (a therm is 1,000 Btu) and an operating time of 150 hr/yr are used, the annual operating cost would be about $20/1,000 sq ft.

James E. Bell

Did I understand that you did not turn the system on until after it had snowed. Why was this?

Winters

On Christmas it snowed and again on Easter, and because all the roads in New Jersey are not heated it took some time to get to the installation. Once we did turn the system on several hours ahead of time, but generally it always happened to snow when no one was available to turn it on.

Bell

Was there any difference in the effect when you had it on earlier?

Winters

The one time when it was turned on before the snow fell, we got a total accumulation of 3 in.; but in the one area where the system was operating, we got a maximum of 1 in. and that soon melted. It depends so much on temperature at the time that I could not say for sure. Yes, it is always better to have it on ahead of time.

Thad M. Jones

Would it be possible to replace all that excavation with something like a cesspool and use that as a big heat sink? How would the size of that compare with the ethylene glycol system?

Winters

You could use a number of different types of reservoirs. Even city water at 50 F could be used and run through the pipes. Sufficient data do not now exist to make size comparisons of the various systems.

M. E. Volz

I have three questions. First, how do you get Christmas off? Second, how do you get Easter off? And third, do you think that a part of your conclusion may be invalid? My reason for asking that question is that we have quite an elaborate electrically heated strip at O'Hare Field. Air temperature does not really seem to affect it nearly as much as wind velocity, dew point, and temperature. As a matter of fact, with regard to the 42-deg water you used, I will guarantee that, at 30 deg with a few degrees spread in the dew point and a fairly substantial wind, the entire thing will be frozen solid. I think the chill factor is far more important than the outside temperature. Do you have any comment on that?

Winters

We do not have any means for measuring wind velocity at our installation. All we can do is measure the air temperature. The reason I said 20 F is that one time as the snow was coming down we melted it, but then, as the temperature dropped below 20 F, it refroze except in certain spots. It had melted directly above the pipes and that froze. It had not melted in between the pipes, and that snow was blown away by the wind. We had the unusual situation of ice above the pipes and clear pavement between.

Nitzberg

These are some figures I have put together for one mile of runway, 150 ft wide by 5,200 ft long, or an area of 780,000 sq ft. With a load of 156 million Btu and using 2 high pressure hot-water boilers having a 75 million Btu output, we can operate 1 hour on 600 gal of No. 4 fuel at 9 cents/gal or $54/hr and guarantee to melt snow within 2 hours.

Lorne W. Gold

It is a little difficult to compare those figures with those that have been presented.

Winters

The 2 installations that we have at the New Jersey Department of Transportation are electrically heated and they are expensive—we are well aware of that. A boiler would be quite a bit cheaper than electrical heating, as you say. In fact our system is designed for a boiler as the next stage. However, the point of this research is to find out whether we can do it with the heat of the earth, which costs nothing.

Gold

From the study you have carried out, is it possible to get some design information on the amount of heat lost into the ground? Can you comment on the advantages of putting insulation under the system to cut down the heat loss into the ground?

Winters

We do have some data available. They are not contained in this report, but we do have temperature data for the surface of the slab and every 2 in. all the way through both the portland cement concrete and the bituminous concrete slabs. So we probably could determine how much heat is lost into the ground from the subbase and base courses. With regard to the insulation, it did not seem to be effective in any way in reducing the heat losses. Apparently there was sufficient heat in the ground to come up through the portland cement concrete slab to melt a little of the snow anyway. The area electrically heated at 20 W/sq ft melted snow just as well as the area electrically heated at 40 W/sq ft where there was a layer of insulation below it. So we found that the insulation was not helping at all.

Minsk

I might comment on some aspects of heating pavements that may not have shown up in the New Jersey work where low temperature fluids were used. If you do use a high temperature fluid to reduce the spacing of pipes and reduce the amount of installation required, there is the requirement for fast response of a higher temperature fluid. The higher the temperature is the better, you might think, because of increased heat transfer and other factors; but thermal stresses that are developed have been shown to increase the deterioration of pavement. This was shown in tests made at Loring Air Force Base several years ago. An installation was so badly broken up from thermal stresses from heat production that the installation had to be abandoned. Low temperature systems, of course, have other drawbacks, but certainly not that of deteriorating the pavement due to thermal stress cracking.